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AN ANALYSIS OF ALTERNATIVE METHODS TO CONDUCT HIGH-RESOLUTION ACTIVITIES IN A VARIABLE-RESOLUTION SIMULATION

by

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AN ANALYSIS OF ALTERNATIVE METHODS TO CONDUCT HIGH-RESOLUTION ACTIVITIES IN A VARIABLE-RESOLUTION SIMULATION

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ABSTRACT

This study analyzes an original hybrid combat simulation for possible use as the underlying support model for the Joint Warfare Systems (JWARS) analytical simulation. The model employs a fixed-increment time advance mechanism but represents individual entities vice aggregated units. Results from an otherwise identical model using a next-event time advance mechanism provide a baseline for comparison. The hybrid, using a longer time increment, runs faster than the next-event model but produces unacceptable results. The hybrid, using a smaller time increment, more closely approximates the next-event model but takes longer to run.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

Decisions facing senior Department of Defense (DoD) officials continue to grow ever more complex. This complexity has led to an increasing reliance on combat models to aid in the decision making process. Since decisions often directly impact lives and livelihoods, it is critical that model results are timely and accurate.

In May 1995, the Deputy Secretary of Defense established the Joint Analytical Model Improvement Program (JAMIP). Their charter is to improve the quality of DoD analytical, theater-level modeling and simulation tools. JAMIP tasked Joint Warfare Systems (JWARS) to design and implement a simulation model of joint, theater-level warfare. JWARS will replace the Tactical Warfare (TACWAR) as the DoD's primary analytical model.

JWARS will represent military units varying in size from corps and divisions to battalions, and possibly companies. Regardless of the size of the smallest organizational unit, designers must employ a method to determine the results of an engagement between units. The results, of course, are ultimately decided by the actions of individual combatants.

The model developed for this thesis can be used to adjudicate battles and update the battlefield and can assume one of two forms, based upon how it manages time within the simulation. The *next-event* time advance mechanism is one in which the simulation clock is advanced to the time of the most imminent future event (e. g., a detection or a shot), then updates the battlefield to account for the fact the event has occurred. Models

using this method may be more accurate since they process events precisely at the time of their occurrence, but may take longer to run.

The *fixed-increment* time advance mechanism is one in which the clock is advanced in set intervals. After each fixed time increment, a check is made to determine if any events should have occurred during the previous interval. If so, the battlefield is updated accordingly. This method may allow a model to run more quickly, but results may contain errors resulting from not processing an event at the precise time of occurrence. For example, suppose it is determined that both a friendly tank and an enemy tank were killed during the previous interval. In actuality, if events were processed at the time of occurrence, the enemy tank may have been killed before it had the opportunity to kill the friendly tank. The next-event mechanism would properly adjudicate the outcome, whereas the fixed-increment mechanism may not.

For this study, two simple combat simulations were constructed. They are identical in every respect except in their handling of the simulation clock. The next-event model results are used as a baseline for comparison. The second model is a "hybrid" fixed-increment simulation. It attempts to combine the attributes of both time advance mechanisms to produce a model that runs faster than the next-event model, yet still delivers acceptable results.

Analysis of the models shows that the hybrid model runs faster when using larger time increments, but the results deviate unacceptably from the next-event model results. It was determined that event sequencing has a significant impact on the results. Smaller

time increments reduced this impact and the results more closely approximated the next-event model results. It, unfortunately, took longer to run.

Continued research of modeling and simulation techniques, in addition to computer hardware development, is required to allow JWARS and other models to deliver the timely, accurate results required by today's senior-level decision makers.

I. INTRODUCTION

Results of combat models and simulations directly impact lives by influencing warfare strategies and the allocation of a multi-billion dollar annual defense budget. When a model predicts a better chance of success for an amphibious assault against an objective rather than an air strike, Marines may be put at risk while the Air Force rests easy. If a simulation indicates "more bang for the buck" from a submarine than a new bomber, assembly line workers in Texas are laid off. Where now stands a thriving community, a Base Closure and Realignment model can help create a ghost town. Because the circumstances surrounding these decisions can be so complicated, models and simulations are used with increasing regularity.

With this increased reliance, it is even more critical today than in the past that the models produce accurate results. The Department of Defense (DoD) realized this, and in May 1995 the Deputy Secretary of Defense established the Joint Analytical Model Improvement Program (JAMIP). Their charter is to improve joint and theater-level modeling and simulation tools used to support senior level decision making in the DoD.

Most senior level decision makers see only a short briefing that is the culmination of months of analysis. Few understand the inner workings of the models used to produce the numbers presented on the view screen, nor should they have to do so. They place their trust in the designers and analysts that developed the model. Therefore, the decisions made during the model's construction phase bear a great deal of the responsibility for the final decision.

Many of the models relied upon for input into the most important decisions are those that operate at the theater level where international coalitions are formed to win major regional contingencies. Corps and divisions clash with the enemy on a grand scale. But as in real battles, it is the actions of the troops in the trenches that ultimately resolve the conflict. In a model, units may be represented, but individuals fight. It is the developers who decide how the outcome of the troops' actions are determined and, in part, whether it is the Air Force or Marines, the submarine or the bomber.

Every decision the designer makes potentially effects the model's results. A clear-cut cause-and-effect relationship must exist between data input and output for a model to have any value. The analyst must be confident that the results are not a consequence of some peculiarity of the model's inner workings, such as the order in which actions are processed or at what points in time the battlefield is updated.

This study focuses on the internal mechanisms of combat simulations; specifically, how time is managed throughout a simulation run and the impact on the results. Also, it analyzes different methods for representing and adjudicating individual combatant actions and the effect of changing the order of processing those actions. It discusses existing methods and proposes a new one. Finally, it addresses issues of speed and accuracy and the trade-offs between the two.

The remainder of this thesis is organized as follows: Chapter II discusses DoD analytical simulations, some simulation basics and simulation clock time advance mechanisms. Chapter III describes the models used in the study. Chapter IV analyzes the model results and discusses their implications and Chapter V offers conclusions and recommendations.

II. BACKGROUND

A. JOINT WARFARE SYSTEM (JWARS)

A major component of JAMIP is JWARS. Scheduled for completion in June 2001, it will be a state of the art, closed-form, constructive simulation of multi-sided, joint warfare for analysis. Users will include the Joint Staff, Office of the Secretary of Defense, Services and other DoD organizations. JWARS will be applied to problems such as force sufficiency analysis, force structure alternatives, joint capability analysis and cost and operational effectiveness analysis of weapon systems. Some joint warfare mission areas that JWARS will represent are command, control, communications and computers (C4), intelligence, surveillance, and reconnaissance (ISR), logistics, direct and indirect fire combat and special operations. [Ref. 1] JWARS will replace the U. S. Army Tactical Warfare (TACWAR) model, the primary theater-level model in use today.

B. SIMULATION

1. General

To answer questions about a real world situation, it would be desirable to duplicate the required circumstances and simply observe. This, of course, is not practical or feasible in all but the simplest cases. Take, for example, a possible JWARS area of analysis: weapons system alternatives. One could not simply observe whether a new missile or aircraft causes more causalities during a theater-level combat engagement. In order to study such questions, models of the systems of interest must be developed.

Many of the models built for these purposes are mathematical in nature, where entities are represented by logical and quantifiable relationships which are then manipulated and changed to observe how the model reacts. [Ref. 2] If the model is simple enough, an analytical solution may be obtained. However, in very complex

situations, such as combat, computer simulations must be employed to adequately address the questions.

Simulations can take many forms and can be classified by how and what they model. Simulations can be either discrete or continuous. A discrete simulation is one in which the state variables change only at a discrete set of points in time. In a continuous model, state variables change continuously over time. Models that contain no random variables are classified as deterministic, while models that have one or more random variables are stochastic. TACWAR is deterministic, JWARS will be stochastic. Simulations can be further classified as static, if they represent a system at a particular point in time, or dynamic, if they represent systems as they change over time. Monte Carlo simulations are static while a model of a restaurant's operations throughout the day would be dynamic.

Models can also be classified by the level of detail to which elements are represented. High resolution models include detailed interactions of individual entities, while aggregated models group individuals into larger units. JWARS will have the ability to represent different organizational levels through data input without a significant change in overall behavior. [Ref. 3] TACWAR primarily represents divisions with some special units, nuclear and chemical, represented as companies.

Mastering the variable resolution issue will be one key to JWARS success. Also, critical to its success is how interactions between the smallest organizational units are resolved.

2. Underlying Support Mechanisms

To determine the outcome of unit interactions at the lowest level, JWARS designers can select from two possible mechanisms; hierarchical and self-contained. Figure 2.1 shows examples of both. [Ref. 4] While the methodologies deal primarily with attrition, they are illustrative of the discussion.

The Combat Analysis Model (COMAN) is an example of an hierarchical structure and Bonder-Farrell demonstrates a self-contained structure. Both are used to generate

estimates of Lanchester equation coefficients. Lanchester equations are discussed in a later section.

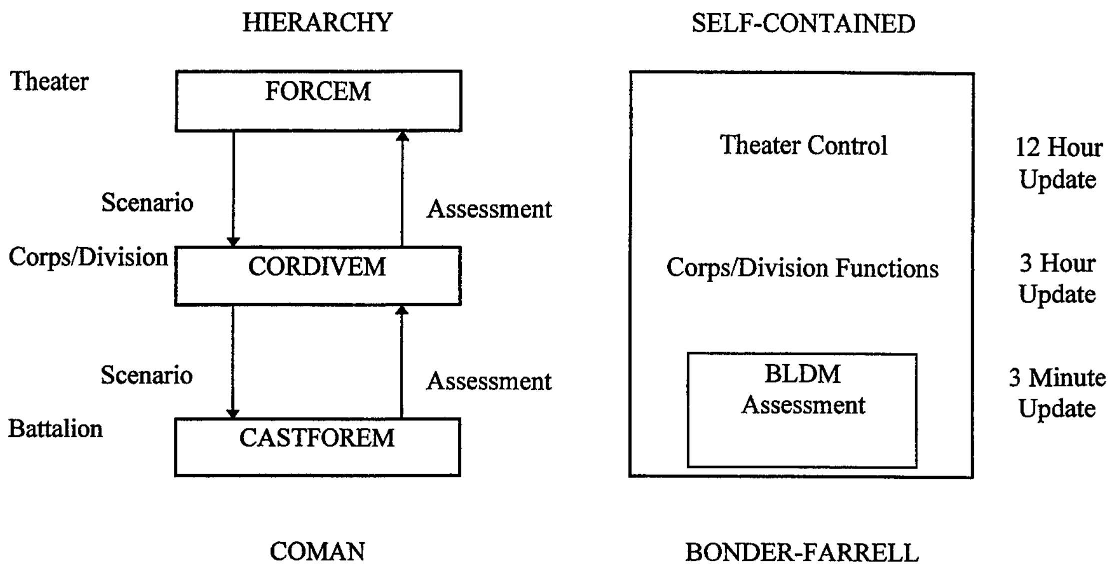

Figure 2.1. Proposed Theater-Level Model Structures

In the COMAN approach, high resolution "feeder" models are run off-line to develop a library of data sets for various combat situations and scenarios. This method allows the time and resource consuming data runs to be conducted outside of the larger model. The disadvantage is that the library almost never contains results from a run conducted under the exact circumstances of the larger model's current situation. As a result, the "closest" run results are used and error is introduced.

The Bonder-Farrell method uses closed-form equations to generate the necessary coefficients during the course of the larger model run. These equations are based on the hypothesis that a battle is simply a collection of one-on-one duels. This method can more closely match the current combat circumstances but at the cost of increased runtime and resources. More importantly, the equations do not account for the synergistic effects between combatants.

Concurrent with the selection of a support mechanism is the decision of what form the underlying model will assume. The following is a discussion of the available options.

3. Time Advance Mechanisms

a. General

JWARS will be a dynamic simulation that represents combat systems over time. Therefore, the form of the underlying support mechanism is largely dependent on how time or more explicitly, the simulation clock, is managed. The two primary ways of advancing the clock are by the next-event and fixed-increment methods.

b. Next-Event Time Advance Mechanism

The *next-event* time advance model is one in which the simulation clock is advanced to the time of occurrence of the most imminent future event (e.g., a detection or a shot) at which point the state of the system is updated to account for the fact that an event has occurred. This process continues until either there are no more events pending or until a prespecified stopping condition is satisfied.

One advantage of this type of simulation is that it skips periods of inactivity, thus avoiding unnecessary checks of the state variables, yet provides a reasonably accurate representation of the system within the context of the model. The problem of event sequencing is reduced since events are processed precisely at the time of occurrence. The next-event time advance model used in this study is described in detail in the next chapter.

c. Fixed-Increment Time Advance Mechanism

(1) General. The *fixed-increment* time advance model is one in which the simulation clock is advanced in increments of exactly Δt time units. After each

update of the clock, a check is made to determine if any events should have occurred during the previous interval. Events occurring during this interval are considered to occur at the end of the interval and the system state is updated accordingly. This method works well for systems with natural fixed intervals such as economic systems or in simulations employing Lanchester equations. It could possibly be faster and less expensive than the next-event time advance model without a loss of accuracy.

A major disadvantage is that errors may be introduced by not processing events at the time of occurrence, resulting in a subsequent loss of sequencing information. For example, it may be determined that tank A and tank B had been killed in the previous interval. However, had the events been processed at the precise time they occurred, tank B may have been killed by artillery before it had the opportunity to kill tank A. Also, the model may require additional "bookkeeping" to track events that take longer than one interval to occur, such as the flight of an aircraft from the airfield to its attack position.

Most fixed-increment combat models apply Lanchester difference equations at the end of a long time period to compute attrition. In TACWAR, for example, Lanchester equations are applied at the end of 12 hour intervals. The remainder of this chapter consists of a short discussion of Lanchester equations and an original "hybrid" model used in this study.

(2) Lanchester Equations. In 1914 F. W. Lanchester formulated two differential equations for specific conditions of war. He hypothesized that casualty rates are proportional to the number of enemy firers and the casualty-exchange ratio depends inversely on the current force ratio. In fixed-increment time advance simulations, his Linear and Square Laws are applied to describe the changes in the force levels of combatants and other significant variables that occurred in the previous interval.

Lanchester equations can be applied in many situations as long as the assumptions required for their use remain valid. Some of reasons Lanchester's

methods are not appropriate as the basis for the JWARS resolution model are briefly discussed below. Readers interested in further study are directed to References 4 and 5.

First, Lanchester equations require coefficients be supplied that are measures of system versus system effectiveness. These coefficients are critical to model performance and it is far from trivial to generate them with accuracy.

Second, Lanchester equations are deterministic and are applied to a fixed increment of time. This is not a problem on its surface. It does, however, invite misuse. The supplied coefficients can be extremely perishable in a combat situation. If the equations are applied to an interval longer than the life of their coefficients, the model outcome can be erroneous. One way of avoiding this danger is to make the time intervals short enough that the coefficients remain valid. Another is to introduce randomness into the model.

Next, models that employ Lanchester equations generate results that are heavily dependent on the number of shooters and only through modifications do they represent other combat factors such as physical conditions, psychological influences or synergistic effects. The impact of these factors is not easily captured but must be accounted for in the next generation of models.

Finally, the equations are applied to aggregated units. This fact was critical to their usage before the advent of low-cost, high-speed, large-memory computers. With the explosive growth, capability and availability of computational tools, modern models are no longer constrained by the need to aggregate elements all of the time.

(3) Hybrid. For the purposes of the study, a model is utilized that combines some of the advantages of the next-event and fixed-interval time advance models. This model is described in detail in the next chapter.

III. MODEL DESCRIPTION

A. GENERAL

This chapter describes the two simulation models used in the study. They both model a two-sided, small unit combat engagement dynamically, stochastically and in high resolution, but differ in their handling of the simulation clock. One uses a next-event time advance method and the other advances time in fixed increments.

The simulations are coded in the MODSIM II programming language. MODSIM II is a general-purpose, modular, block-structured high-level programming language which provides direct support for object-oriented programming and discrete-event simulation. It is a strongly typed language with a general structure similar to Pascal or Ada. In MODSIM II, simulation is supported by a library module which contains a number of objects and support procedures. All objects are allowed to perform actions which elapse simulation time.

Commonly available spreadsheets and other programming languages, such as Pascal and FORTRAN, were considered but not selected since it was felt they did not adequately handle the clock and the large number of object interactions anticipated. Java was also considered, but the author's familiarity with MODSIM II and its powerful flexibility, allowing for future changes and upgrades, ultimately led to its selection. MODSIM III is the current version but is not available or supported at the Naval Postgraduate School.

Copies of the models may be downloaded from the World-Wide Web by following the links from "http://web.nps.navy.mil/~ahbuss".

B. NEXT-EVENT TIME ADVANCE MODEL

1. General

The following definitions apply throughout the discussion. A system is a collection of entities that interact toward the accomplishment of some logical end. The state of the system is the collection of variables necessary to describe the system at a particular time relative to the study's objectives. Finally, an event is the instantaneous occurrence that may change the state of the system. [Ref. 2]

This model advances the simulation clock to the time of occurrence of the most imminent future event (e.g., a detection or a shot). At this point the state of the system is updated to account for the fact that an event has occurred. Specifics of the next-event time advance model are described below.

2. Statement of Algorithm

All model data and simulation parameter values are read from input files and are described in a later section. All combatants are initialized and placed in their starting positions and individual vehicle routes are computed.

The simulation clock begins with the lead vehicle's movement toward the opposing force. For each segment of a vehicle's route, the simulation schedules detections between sensor-target pairs, as appropriate.

Each shooter maintains a detection list and builds a target list by adding detected targets that are within maximum weapon range. The shooter selects and fires at, or engages, the best target on its list. If a detected target is outside the range of any direct fire weapon, indirect fire weapons (i.e., artillery or helicopters) are employed. The firing process follows a shoot-look-shoot scheme and a shooter has perfect information about its target.

Each battle continues until all the vehicles reach their final checkpoint or are killed in their effort. The simulation clock, combatants' states and appropriate statistical

counters are reset and the next run conducted. Measures of effectiveness (MOE) are output upon the completion of a set of runs.

a. Battlefield

Locations on the battlefield are referenced by an (x, y) coordinate with units in kilometers. Altitude, terrain features and weather have not been incorporated in this initial version, but the model is designed to easily accommodate their inclusion.

b. Scenario

The model's flexibility allows for a variety of different scenarios and force compositions made possible through the use of the data input set. The following is a description of the scenario used for this study. Figure 3.1 shows an approximation of the initial battlefield configuration. A FAARP is a helicopter Forward Area Arming and Refueling Point.

There are two opposing forces, red and blue. The blue force assumes an offensive posture and is comprised of a company of thirty-three tanks, a scout platoon of five armored personnel carriers (APCs), six artillery guns in direct support, a section of two fixed-wing aircraft and a section of two helicopters. The red force assumes a prepared defensive position and is comprised of sixteen tanks, six artillery guns in direct support and an air defense site in general support.

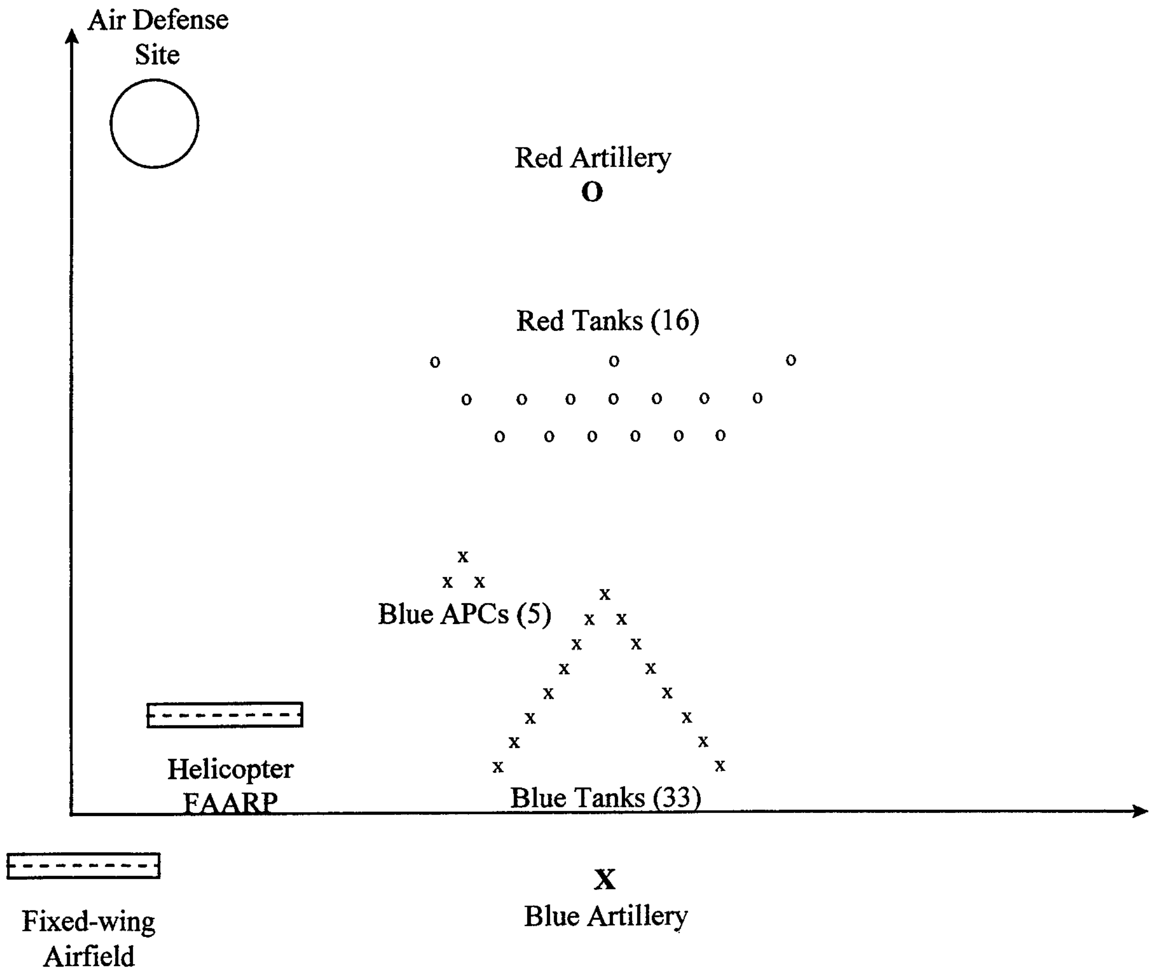

Figure 3.1. Initial Battlefield Conditions

Each run follows the same general pattern. The red tanks detect the blue APCs and call for fire support. The leading blue APCs locate red's position and call for fire support. Blue artillery and helicopters engage the red maneuver vehicles. A wedge of blue tanks follows and both sides conduct a savage direct fire engagement while the artillery shifts to counterbattery fires and the fixed-wing aircraft engage the air defense site. The fight continues to a specified breakpoint for one or both sides.

c. Combatants

(1) Definitions. The term "combatant" refers to a tank, APC, artillery, aircraft or air defense weapon. "Maneuver vehicle" refers to a tank or APC.

(2) Tanks and APCs. A maneuver vehicle's route is precomputed based on the lead vehicle's route, the prescribed formation and the vehicle's position in the formation. The blue tanks and APCs travel toward red's position at maximum speed along linear segments defined by user input checkpoints. A dead vehicle remains at the location at which it was killed. Route selection and speed cannot currently be altered within a run or series of runs.

Existing combat models provide a basis for the target acquisition method used. Current high resolution models JANUS and the Combined Arms and Support Task Force Evaluation Model (CASTFOREM), among others, employ a model developed by the U. S. Army's Night Vision and Electro-Optical Laboratories (NVEOL). It includes many different real-time direct imaging sensor devices and considers degraded visibility environments. If JWARS were to employ a high resolution model, this method would most likely also be used.

Assumptions needed for the NVEOL model are that the target must emit or reflect a detectable signature that is transmitted to the sensor. The sensor must be pointed at the target and then must process the signature to form an image of the target. The human observer views the displayed image and makes some response.

The probability of detecting the target in time t is a cumulative exponential density function modified to account for the probability that the observer viewing the image on his sensor will notice it, given an infinite amount of time. The equation is,

$$P_d = P_\infty * (1 - e^{-ct}) \tag{3.1}$$

where c is a search rate computed from the relative sizes of the field of view and the field of search. [Ref. 4]

In this study, the target acquisition process is based on a continuous looking model. Each combatant has a circular search area defined by its search radius. Line-of-sight is currently assumed to exist to any target within the search area. When a blue vehicle moves toward its next checkpoint, the simulation determines whether its search area intercepts any red target. If so, a future detection event is scheduled.

Random times to detect are computed using the cumulative distribution function of the exponential distribution,

$$F_T(t) = 1 - e^{-\lambda t} \tag{3.2}$$

The detection rate parameter, λ, is estimated using the DYNTACS model developed in the 1960s. [Ref. 4] It is a combination of the factors that were later considered separately in the NVEOL model. It is estimated by

$$\lambda = P_0 * (-0.003 + (1.088 / K)) \tag{3.3}$$

and

$$K = 1.453 + \tau * (0.05978 + 2.188 * R^2 - 0.5038 * CV) \tag{3.4}$$

where the observation conditions are described by

τ = terrain complexity code (1-7).
R = apparent range in kilometers.
CV = crossing velocity in meters/second.
P_0 = probability that the observer is looking in the 30° sector containing the target.

If a course change occurs before the target enters the search area, the previously scheduled detection is canceled. If a course change is made after entry into

the search area, the previously scheduled detection remains on the event list. If a target is detected but outside of the sensor's maximum weapon range, the target is passed to the fire support coordination center (FSCC).

A target is removed from the detection list if the searcher or target is killed or the target is no longer within the search area. Detections of blue combatants by red combatants follow the same process.

A target is added to a shooter's target list if it meets two requirements. It must be on the shooter's detection list and it must lie within the circular engagement area whose radius is defined by the shooter's maximum weapon range.

The addition of a target to the shooter's target list begins the firing process. First, the best target is selected from the list. For this study, best is defined as the target with the highest priority with ties broken by relative proximity. Target priorities are data input items. A value of "1" is assigned to a target type that the shooter will engage first, followed by target types with priority "2", and so on. A shooter's cycle time is determined by its weapon's rate of fire. Engaging a new target or switching targets imposes an additional fixed delay time that is input by the user. When a round is fired, the shooter's ammunition supply is decremented and the results of the shot assessed.

Impact projectiles without fragmentation must score a direct hit on a target in order to kill the target. Thus, the P_k can be decomposed into an accuracy component and a lethality component.

$$P(kill|shot) = P(kill|hit) * P(hit|shot) \tag{3.5}$$

Some models acquire these data from lookup tables compiled by the Army Research Lab (ARL). ARL data are the result of high resolution engineering simulations of a single round hitting various components of a target vehicle to derive these conditional probabilities. [Ref. 6]

For simplicity, this model only requires one input, P_k, for each firer type i, target type j pair. It is a combination of the probability of a hit and kill at maximum weapon engagement range. The model can be modified later to utilize both

components. The input P_k for each firer type, target type combination is then adjusted for separation range using an adaptation of Bonder's range dependent attrition equation.

$$P_k(r) = P_{k_0} * (1 - r / r_{\max})^u \tag{3.6}$$

Figure 3.2 is a plot of the shaping exponent. When $u = 1.0$, P_k decreases linearly with range. This approximates the lethality of a tank main gun. A value of $u > 1.0$ causes lethality to drop off more rapidly with range similar to small arms weapons. On the other hand, a missile's killing ability is relatively constant until it approaches its maximum range and would have a exponent of $u < 1.0$. [Ref. 6]

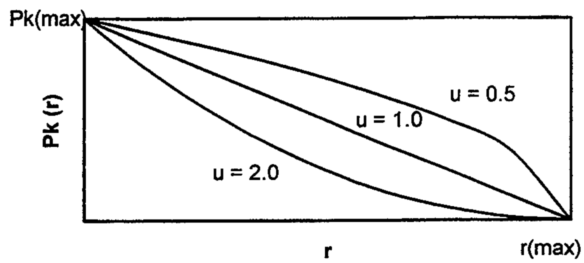

Figure 3.2. Bonder Range Dependent P_k.

If a random number drawn from a uniform(0, 1) distribution is less than the adjusted $P_k(r)$, the target is declared killed.

ARL data are available that can be used to assess the kill categories:

• K-kill	Damaged beyond repair or to the extent that repair is not economically feasible.
• M-kill only	Damaged so that the vehicle is uncontrollable and is not repairable by the crew on the battlefield.
• F-kill only	Defeat of the main armament.
• M/F-kill	Either a mobility or a firepower kill.
• MF-kill	Both a mobility and firepower kill.

This model currently assesses only K-kills but could easily be upgraded to include multiple kill categories. Currently, a target's kill is known to all and, therefore, removed from all detection and target lists, and all applicable pending events are canceled. If the shooter has ammunition remaining, it will begin another firing process. Otherwise, the shooter will fire no more rounds since resupply for maneuver vehicles currently is not modeled.

(3) Artillery. Artillery positions do not change within a run or series of runs, nor does artillery directly detect maneuver vehicles. Rather, the detection and target lists are built from the forward observation capability described in paragraph c.(2). Artillery does, however, detect the opposing artillery in a random, exponentially distributed length of time after the first salvo is fired, simulating a counterbattery radar capability.

It is important to note that the artillery in this model performs both direct and general support roles. Fires will directly support the engaged tank companies and conduct counterbattery fires. If this model were incorporated into a larger model, the artillery role would be more stringently defined. Generally, artillery assets at the division level or higher provide general support to smaller units unless assigned a direct support role for a particular mission.

The firing process is the same as for the maneuver vehicles except the delay time assessed for changing targets is the time to fire one salvo (currently six rounds). Also, if the artillery is hit, its relative strength is degraded by an input percentage and is assumed inoperative once the percentage falls below a prescribed breakpoint. A decrease in its percent strength proportionally degrades its rate of fire.

(4) Aircraft. The FSCC will assign a target to the helicopter section if it is not already on a mission and the artillery is unavailable. A prescheduled detection (assumed to be from an outside source) of the red air defense site prompts a launch of the fixed-wing section.

Aircraft movement is similar to the maneuver vehicles but differs in the method of route selection. The simulation selects the attack position (AP) nearest the assigned target from an input list. The aircraft move at maximum speed in a two-dimensional straight line to and from that AP. While on a mission, aircraft can detect "targets of opportunity" in the same manner as the maneuver vehicles. Aircraft can change APs if target selection dictates.

The firing process is the same as for the maneuver vehicles except aircraft fire only from an AP. Also, if an aircraft is hit and killed, the entire section is considered killed. Dead aircraft remain at the location they were killed.

An aircraft section remains airborne while there are targets on its target list and has fuel and ammunition remaining; otherwise, it returns to base. The section is resupplied upon its return and is eligible for another mission after delaying for a fixed amount of turnaround time.

(5) Air Defense. The red air defense position does not change within a run or series of runs. It only detects and engages aircraft. The firing process remains the same as for other combatants. Hits against the site are assessed in the same manner as for artillery.

3. Input

Table 3.1 lists required data input items and sample parameter values. In the column headed "Input Item", items such as "target priority" require one value for each opposing combatant type. The example below assumes six types, thus the notation (1-6). The table does not show every item; notably, individual initial positions, lead vehicle routing or aircraft APs are not shown. A complete listing of the data can be found in the appendix.

Input Category	Input Item	Sample Value
Simulation Parameters	Number of Runs	20
	Number Output Iterations	100
	Interval Length (hr)	0.01
Combatant Type 1 Data	Type	Blue Tank
	Number	33
	Speed (kph)	15.0
	Search Radius (km)	4.0
	Weapon Type	3
	Max Ammunition	40
	Target Priority (1-6)	2 3 4 1 99 99
	Detection Rate (per hr, 1-6)	120 90 10 10 0 0
Weapon Type 1 Data	Type	Tank Main Gun
	Max Range (km)	2.0
	Firing Rate (rnds/min)	1.5
	Shaping Coefficient	1.0
	Pk (max, 1-6)	0.4 0.4 0.5 0.2 0.0 0.0
Miscellaneous	Artillery Degrade Factor	0.9
	Artillery Breakpoint	0.5
	Aircraft turnaround (hr)	0.4
	Air Defense Detection (hr)	0.3

Table 3.1. Input Requirements and Sample Values

4. Output

Several MOEs can be captured and output for analysis. One portion of a sample output is shown in Table 3.2. The sample presented here is uncharacteristically small and used only for illustrative purposes.

It begins with basic experiment data to control run length. The number of output intervals times the length of an interval gives the total simulation time for each run, in this case 1.0 hours.

Next, measure of effectiveness (MOE) data is output. MOEs are discussed in the next chapter. The type of results and presentation can be changed by modifying the simulation code.

Number of Runs		50			
Number of Output Intervals		4			
Length of Interval (hr)		0.25			
SimTime	Mean Surviving Red Tanks	Mean Surviving Blue Tanks	Mean % Strength Remaining Red Arty	Mean % Strength Remaining Blue Arty	Mean % Strength Remaining Red ADA
0.00	16.00	33.00	1.00	1.00	1.00
0.25	15.47	32.20	0.96	0.98	1.00
0.50	12.18	18.96	0.84	0.81	0.95
0.75	5.47	12.20	0.66	0.68	0.88
1.00	2.18	8.96	0.64	0.61	0.55
Number of Blue Wins		31			
Number of Red Wins		29			
			Number of Times Killed		Mean SimTime Killed
Helicopters			24		0.47
Fixed-wing			26		0.69

Table 3.2. Sample Simulation Output

5. Possible Future Upgrades

As stated earlier, one of the reasons for selecting MODSIM II as the programming language is its flexibility. Its modular design and object-oriented capabilities allow for continuous, relatively easy upgrading. Some aspects of the model identified for further improvements are:

- Incorporation of a terrain data base.
- Model effects of weather and other battlefield obscurations.
- Allow dynamic route selection and speed and formation changes.
- Utilize a more robust detection process.
- Include various kill categories such as mobility and firepower kills.
- Expand the role of logistics.

C. FIXED-INCREMENT TIME ADVANCE MODEL

1. General

The fixed-increment time advance model advances the simulation in increments of exactly Δt time units. This model is very similar, by design, to the next-event time advance model. Therefore, the following description covers only those areas that differ from the discussion in section B.

2. Statement of Algorithm

Battlefield setup and combatant initialization remains the same. There are three major actions occurring in each Δt time unit; moving (M), detecting (D) and shooting (S). All combinations of runs are possible by simply interchanging three lines of code. This "sequencing", as will be shown Chapter IV, has an effect on the model results and warrants further discussion. Table 3.3 shows an example of three of the six possible sequences over the first three increments of a run.

Sequence	Increment 1 t = [0.0 hr, Δt hr]	Increment 2 t = (Δt hr, $2\Delta t$ hr]	Increment 3 t = ($2\Delta t$ hr, $3\Delta t$ hr]
1	MDS	MDS	MDS
2	SMD	SMD	SMD
3	MSD	MSD	MSD

Table 3.3. Partial List of Major Action Sequences

Sequence 1 makes the most intuitive sense. First, at time Δt, all the shooters update their positions. Next, they build detections lists at their new positions and then build target lists from their current detection lists. Finally, they shoot at their best target. This sequence repeats for each increment.

At the end of the first increment of sequence 2, the shooters' first action is to shoot. However, since their positions have not been updated and no detection lists built, their target lists are empty. The first opportunity to kill an opponent is at the end of the second increment. The effect of sequence 2 is actually the same as sequence 1 delayed one Δt time increment. This delay could conceivably affect model outcome.

Sequence 3 demonstrates a more serious problem. At the end of the first increment, the shooters update their positions, do not shoot due to the empty detection and target lists, and lastly, build detection lists at that position. There were detections after one increment but no shots due to the event sequencing. At time $2\Delta t$ hours, the shooters update their positions, then shoot at targets from target lists derived from detection lists built in the last increment at their last position. Realistically, the best target may not even be detectable from the shooter's updated position. The other sequences offer similar problems. In this small model, the best sequence is easily determined but in larger models the sequencing problem may not be so obvious. The remainder of the model description discusses the MDS sequence.

For each time step, the clock is advanced one time unit of length Δt and each combatant's position is updated. Each possible red-blue pairing is examined and a determination of whether a detection occurred in the preceding interval is made. A target list is then constructed for each combatant and the engagements are adjudicated.

This process is repeated for the specified number of intervals. The simulation clock, combatant's states and appropriate statistical counters are reset and the next run is conducted. MOEs are output upon completion of all runs.

a. ***Battlefield.*** No differences from next-event model.

b. ***Scenario.*** No differences from next-event model.

c. ***Combatants***

(1) Definitions. No differences from next-event model.

(2) Tanks and APCs. Routing, speed and formations remain the same. Positions are updated only at the end of each interval. Dead vehicles remain at the position they were in at the end of the interval in which they were killed.

Each shooter-target pair is examined for possible detection. The separation range between each red and blue combatant is computed. If the target is within the shooter's search area, a probability of detection (P_d) is computed based on the exponential cumulative distribution function (equation (3.2)). This model uses the same estimations of λ as the next-event time advance model. If a random draw from the uniform (0, 1) distribution is less than the P_d, the target is added to the sensor's detection list. Targets detected during a previous interval remain on the shooter's current target list.

Each target list is cleared before for the current interval's list is built. If a target is on the shooter's detection list and is within its weapon's engagement range, it is added to the shooter's target list. Next, the best target is selected and the number of shots allowed in the interval is computed.

The number of shots is the minimum of the number of rounds remaining and the number of shots possible based on the weapon's firing cycle and the

interval length. If the number of shots includes a fraction of a round, the full rounds are fired first.

Engaging a new target or switching targets imposes an additional fixed delay time that is input by the user. The shooter engages the target until it fires the number of shots allowed or until it knows it killed the target. The P_k calculation remains the same as for the next-event model. The result of the fractional round is assessed using a P_k proportional to the fraction of the round fired.

All shooters alive at the beginning of an interval are allowed to shoot and be shot at the end of the interval. A combatant's status is updated at the end of the interval. This, of course, permits possibly dead shooters to shoot and for targets to be killed multiple times in an interval.

(3) Artillery. All activities remain the same except that counterbattery detections are carried forward.

(4) Aircraft. No differences from next-event model.

(5) Air Defense. No differences from next-event model.

3. Input. No differences from next-event model.

4. Output.

In addition to the next-event time advance output, this model outputs the number of kills made by each tank. This number is used to compute the number of "overkills". Overkills are discussed in Chapter IV.

5. Possible Future Upgrades. No differences from next-event model.

IV. ANALYSIS

A. GENERAL

The next-event and fixed-interval models were run using identical scenarios and data sets. The goal was to obtain reasonable results from two simulations that are identical except in their time advance mechanisms so that the results could be compared.

The results from next-event model serve as the baseline for these comparisons. The analysis is divided into two categories: the effect of varying interval length and the effect of varying major event sequencing. A summary discussion of the results completes the section.

B. VERIFICATION

Verification is the process of determining that a model implementation accurately represents the developer's conceptual description and specifications. [Ref. 7] The models in this study were designed for the specific purpose of examining alternative methods of processing high-resolution activities in a variable-resolution simulation. They represent an array of combat activities, yet are simple enough as to not complicate comparisons or mask differences.

The next-event model was designed and implemented first. Major actions, (i.e., moving, detecting and shooting), were developed and tested separately with small data sets and scenarios. Once they performed satisfactorily, they were combined and tested in unison. Output data were subjected to face validation. Unreasonable results caused by errors in logic or coding were corrected.

The fixed-increment model was created and tested in a similar fashion. Once both models appeared to be correct, their results were compared. Anomalies were again examined and errors corrected. The final models appeared to be correctly implementing their respective approaches.

C. DATA

A complete list of the data used for the final model runs can be found in the Appendix. Data such as combatants' initial positions, speeds and routing were selected as a result of the author's experience. Numbers of combatants, search radii, rates of fire and P_k values were set and adjusted to achieve reasonable results.

Detection rates for sensor type i, target type j pairs were computed using equations (3.3) and (3.4). The detection rate for a blue attacker detecting a red defender is 27.82 detections/hour when using $\tau = 1$, $R = 3.0$, $CV = 0$, and $P_0 = 0.16$. The red defender is given a three-to-one advantage when detecting the blue attacker or a detection rate of 83.46 detections/hour. All data may be easily modified for the conditions of the particular study.

D. NUMBER OF REPLICATIONS

To determine the number of replications required, the next-event model was run until the half-width of the $100(1 - \alpha)$ percent confidence interval of the number of red tanks at time 0.75 hours was less than or equal to a specified precision of 0.10 tanks (i.e., the half width was ≤ 0.10 tanks). Figure 4.1 shows the desired precision is reached after forty-five runs. Therefore, fifty runs were used for each case.

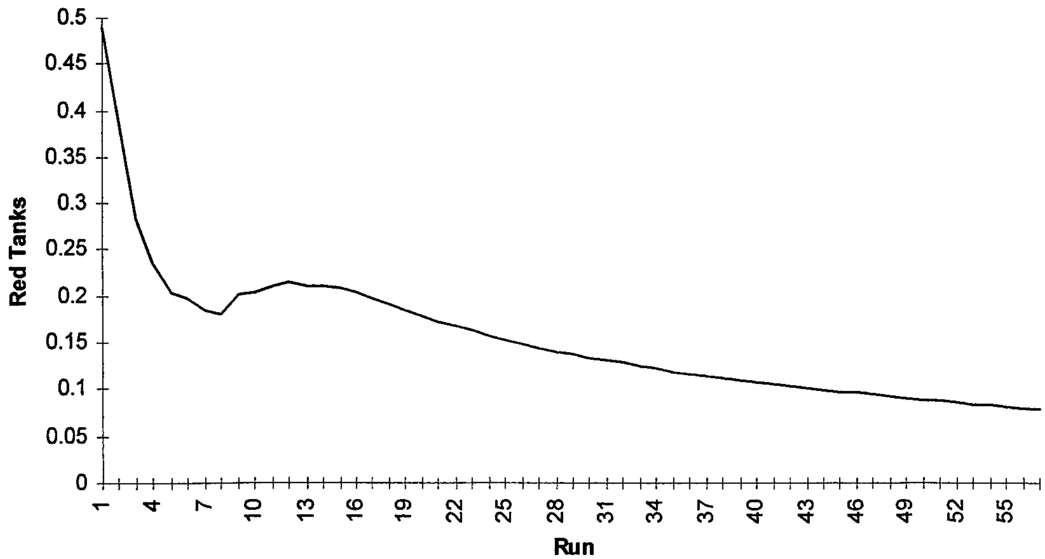

Figure 4.1. Results of Precision Runs

E. MEASURES OF EFFECTIVENESS

The following MOEs were used for the analysis:

1. Mean number of surviving blue tanks
2. Mean number of surviving red tanks
3. Winner
4. Overkills
5. Runtime

One side is declared to be the "winner" if that side kills all of the opponent's tanks. There can only be one winner at most during each run.

Overkills can occur only in the fixed-increment model since combatant status is updated only at the end of the engagement process of all combatants. This allows for the possibility that a tank can be killed multiple times in one Δt time increment. In the next-event model, a combatant's status is updated at the precise time of the kill, thereby disallowing overkills.

F. VARYING INTERVAL LENGTH

Three different interval lengths (Δt) were used: 0.0025 hours , 0.005 hours and 0.01 hours (9, 18 and 36 seconds, respectively). Figures 4.2 shows a plot of MOE1, the mean number of surviving blue tanks. All runs of the fixed-increment model in this section use the MDS sequence.

The battle begins with the blue tanks following in trail of the scouting APCs. The tanks enter the red tanks' search radii triggering a relatively ineffective red artillery attack at time 0.35. The direct fire battle begins at time 0.44 when the blue tanks close within the red tanks' initial opening ranges. A violent battle ensues for the next 0.30 hours. At time 0.75 the battle nears completion either because one side has killed all of the opposing maneuver vehicles or the surviving blue tanks have passed through red's position enroute to their objective.

Figure 4.3 shows a plot of MOE 2, the mean number of surviving red tanks. The blue scouts detect and direct support artillery fire against red tanks beginning at time 0.25. Since multiple indirect fire targets are available, the blue FSCC launches helicopters for additional support. The helicopters have better success than artillery during their participation from time 0.46 through time 0.56. Beginning at time 0.50, red tanks are engaged and killed by blue tanks.

There are obvious differences in the rate of killing blue tanks, and to a lesser extent the killing of red tanks, during the direct fire battle depending on the length of Δt. Both plots show large differences in the final mean number of surviving tanks. More blue survivors result in less red survivors for obvious reasons; hence, the changing of relative positions of Δt lines between Figures 4.2 and 4.3.

A plot of the standard deviation of the number of surviving blue tanks, Figure 4.4, shows that it is smaller but more erratic in the next-event model than the fixed-increment model. Also, the fixed-increment model run with a larger Δt had a smaller average standard deviation than with a smaller Δt.

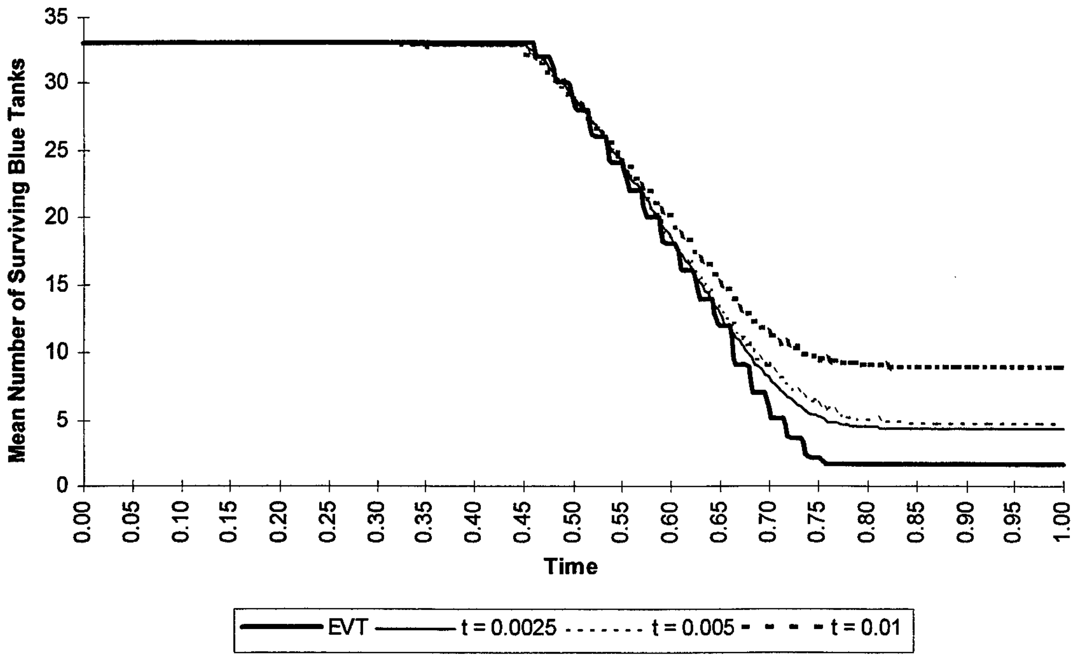

Figure 4.2. MOE 1 : Mean Number of Surviving Blue Tanks

Another obvious difference, apparently as a result of varying Δt, emerges from the plot of MOE 3, winner, in Figure 4.5. The proportion of battles won by blue increases as Δt increases. These differences can be explain by considering the number of overkills in each model. Tables 4.1 and 4.2 summarize the results for blue and red overkills, respectively.

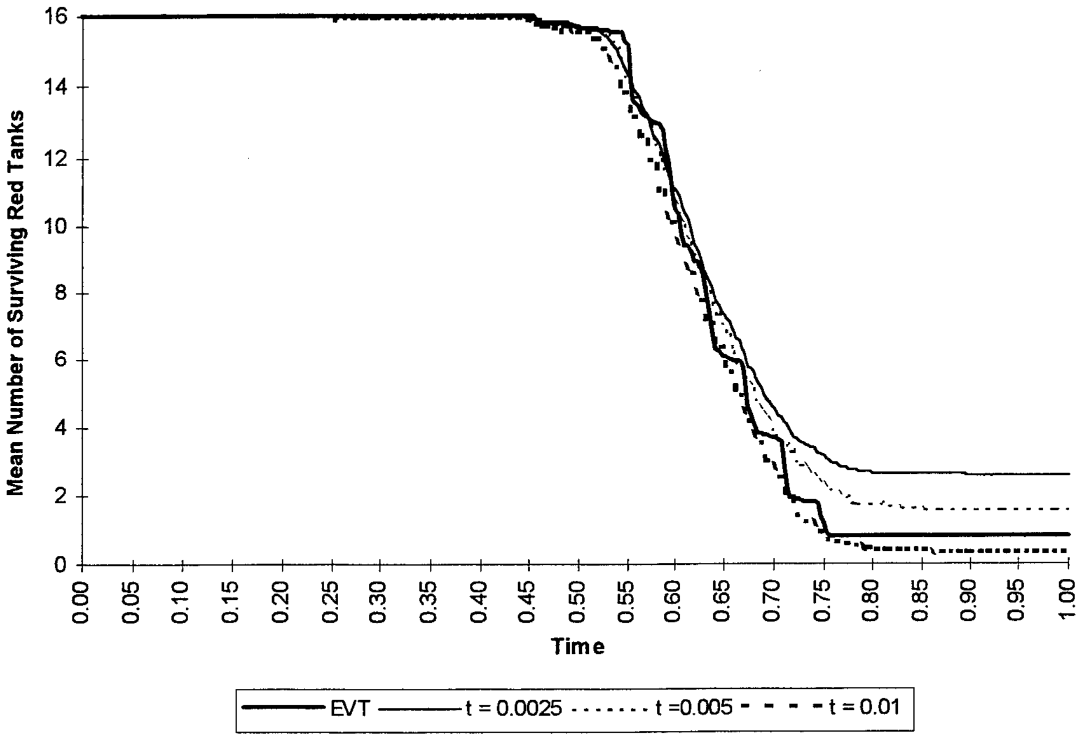

Figure 4.3. MOE 2 : Mean Number of Surviving Red Tanks

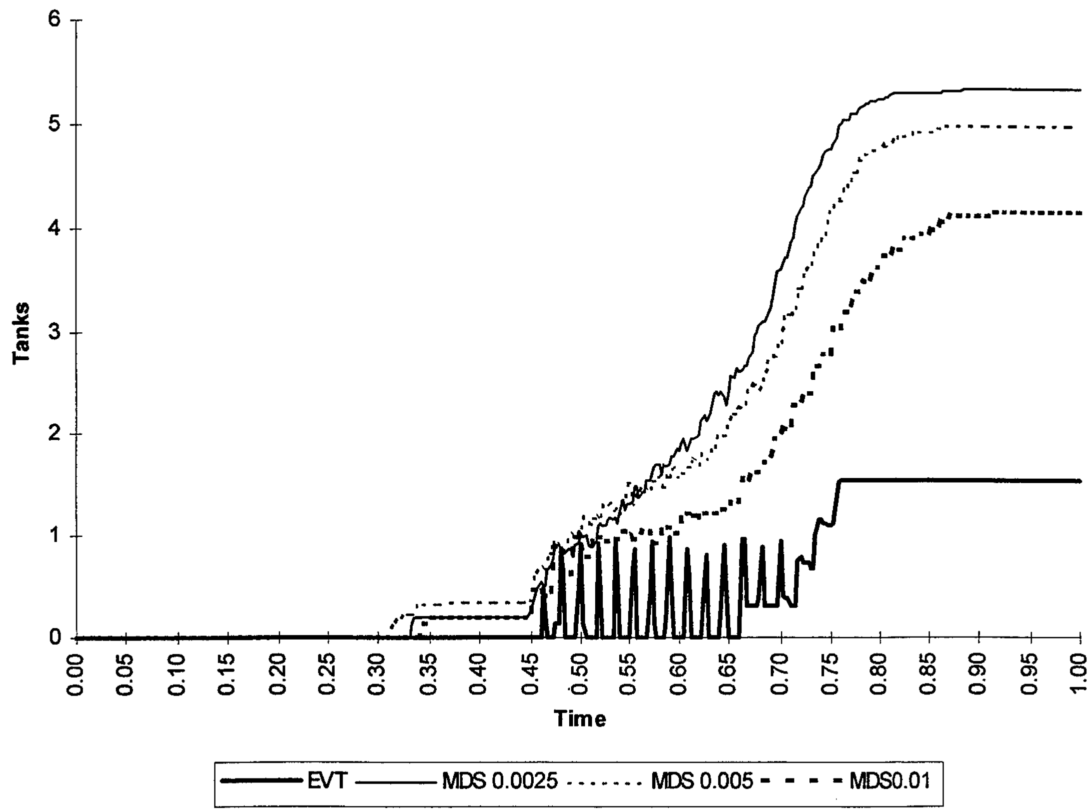

Figure 4.4. Standard Deviation of the Number of Surviving Blue Tanks

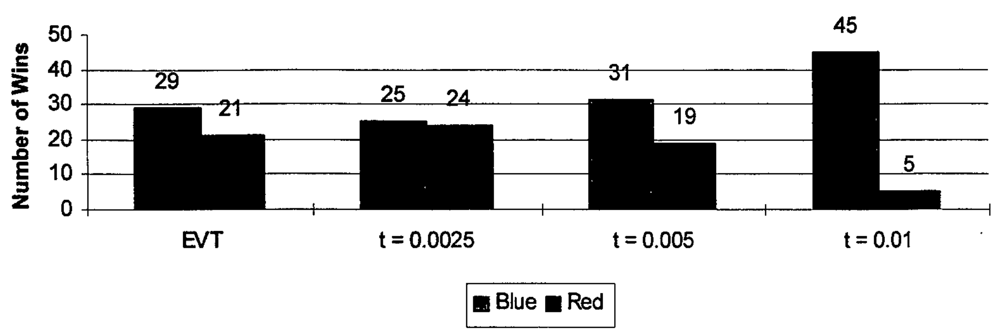

Figure 4.5. MOE 3 : Winner

Δt (hours)	Mean Number of Surviving Blue Tanks at t = 0.0	Mean Number of Surviving Blue Tanks at t = 1.0	Difference Between t = 0.0 and t = 1.0	Mean Total Number of Blue Tanks Killed	Overkills
0.0025	33.00	4.32	28.68	32.70	4.02
0.0050	33.00	4.80	28.20	36.80	8.60
0.0100	33.00	8.94	24.06	41.88	17.82

Table 4.1. MOE 4 : Blue Overkills

Δt (hours)	Mean Number of Surviving Red Tanks at t = 0.0	Mean Number of Surviving Red Tanks at t = 1.0	Difference Between t = 0.0 and t = 1.0	Mean Total Number of Red Tanks Killed	Overkills
0.0025	16.00	2.58	13.42	14.08	0.66
0.0050	16.00	1.60	14.40	15.86	1.46
0.0100	16.00	0.34	15.66	19.38	3.72

Table 4.2. MOE 4 : Red Overkills

Before discussing observations of the results, the engagement process of the fixed-increment model is recalled from the previous chapter. A tank shoots at another tank if it is the best target on its target list. It continues to fire until it shoots all its ammunition allocated for that interval or until the shooter knows that it has killed its target. If the shooter kills its target and has ammunition remaining, it engages another target after a time delay is assessed for switching targets. The best target is the closest target on its target list, and the closer the target is, the higher the P_k is against it. With the longer Δt, a shooter has more opportunities to kill a target while a higher P_k is in effect, resulting in more kills.

There are two observations of these results. The first is that the mean total number of kills increases with increasing Δt. The second observation is that the number

of overkills increases with increasing Δt. The important fact is that, although the shooter knows that it has killed its target, no other shooter knows of the kill since combatant status is updated only after all shooters have had an opportunity to fire. This is a reasonable assumption since all events are assumed to occur simultaneously at the end of the increment. Other fixed-increment models, including those that employ Lanchester-type attrition methodologies, make the same assumption. This result highlights a major shortcoming of fixed-increment simulations; all events that are determined to have occurred in the previous Δt time increment are assumed to have occurred simultaneously at the end of the increment causing critical sequencing information to be lost.

As a result, in this model combatants can be killed multiple times in one increment even though it may have killed its own killers first. The longer the increment, the more opportunities for multiple kills there are. Furthermore, the more multiple kills there are, the less efficient the shooting side will be at killing. The model utilizing the shorter time increment updates the combatant status more frequently, losing less sequencing information, and produces results closer to the next-event model. The red forces waste more time overkilling blue because there are more blue targets than red and, therefore, blue performs better than red in long time steps. A fixed-increment time advance model using smaller Δt time increments should more closely approximate the results of the next-event time advance model as shown in Figure 4.2. The most important observation may be that, assuming all other factors being equal, by simply changing Δt by a matter of seconds, the model results can change drastically.

Finally, Figure 4.6 shows a plot of time to complete 50 runs of the next-event time advance model and the fixed-increment time advance model with the three values of Δt. Not surprisingly, the runtime for the model depends on increasing or decreasing Δt. The next-event model runtime falls between the fixed-increment model using $\Delta t = 0.0025$ and 0.005.

G. VARYING EVENT SEQUENCING

The model's three major activities are moving, detecting and shooting. In the next-event time advance model, events are processed in the order they occur. In the fixed-interval model a decision must be made on which order the events are processed. For purpose of analysis, the model is run for each possible sequence. Figures 4.7 and 4.8 show the plots of MOE 1 and MOE 2 for three of the sequences. All runs of the fixed-increment model in this section use Δt = 0.005 hours because this increment produced results reasonably close to the next-event model for MOEs 1,2 and 3.

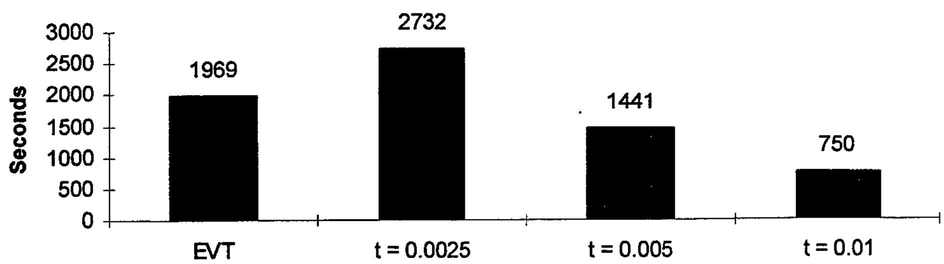

Figure 4.6. MOE 5 : Runtime

General descriptions of the plots remain the same as in the preceding section. They also show different results can be obtained by varying the sequence of events. In this model the events are rather obvious and the sequence move, detect, shoot probably best represents "reality". The warning is that in a large model where it is not so clear what should be done first or when the order may not seem important, the sequencing of events may skew the results.

A plot of MOE 3, Figure 4.9, further demonstrates this point. Every different sequence produced a different combination of wins. The plot graphically illustrates the effect of the sequencing dilemma discussed in the preceding chapter. Each of these results is different because at some point during an individual run the state variables were

such that one side achieved enough of an advantage to eventually win that particular battle. This occurred enough time during a set of runs to produce the different outcomes.

This also begs the question, which results are correct? Is the intuitively comforting sequence MDS correct or is it SMD, the sequencing that produced the same results as the next-event model for this MOE? It is not clear that these questions can be satisfactorily answered. Maybe all that can be said is that analysts using the results of a model employing a fixed-increment time advance model should be aware that peculiarities of the model rather than the changing input data may be responsible for the different results.

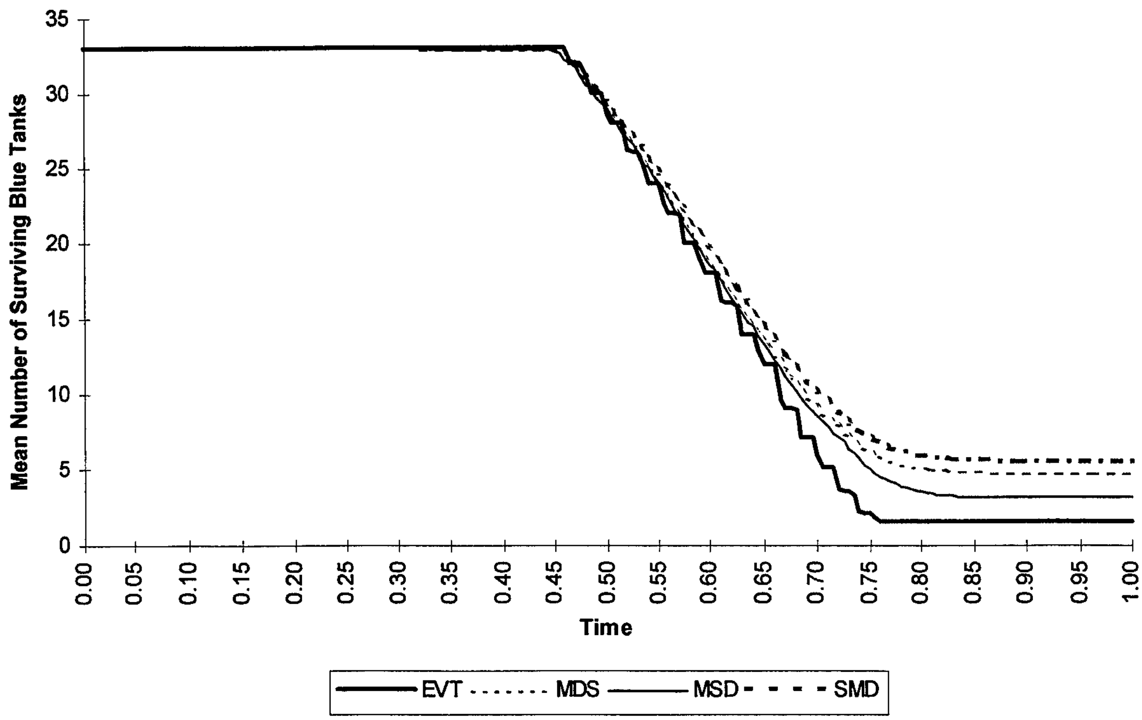

Figure 4.7. MOE 1 : Mean Number of Surviving Blue Tanks

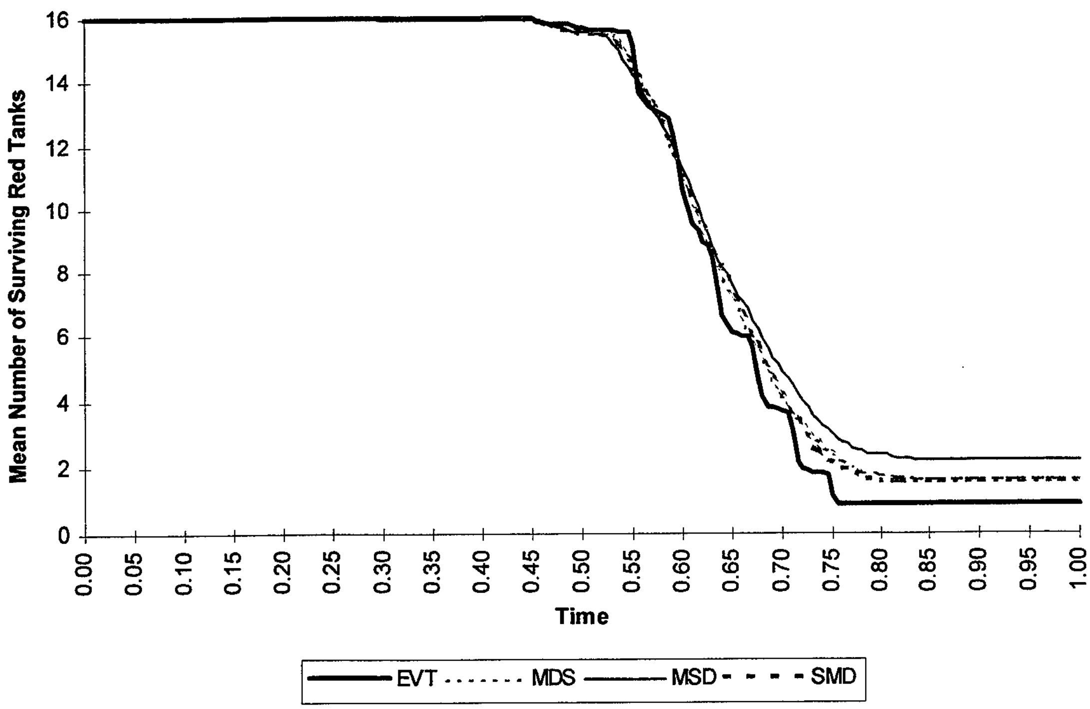

Figure 4.8. MOE 2 : Mean Number of Surviving Red Tanks

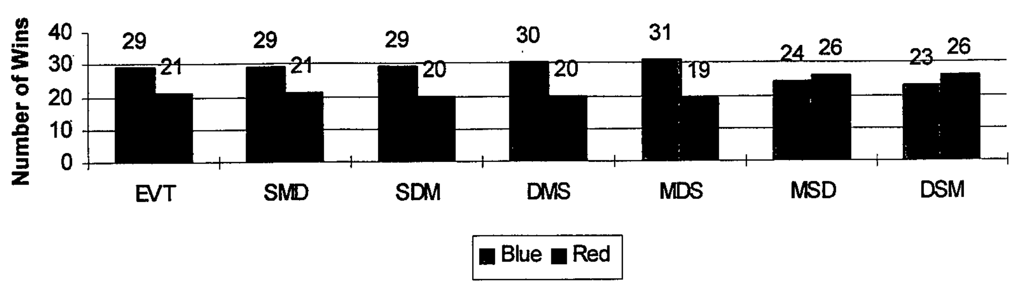

Figure 4.9. MOE 3 : Winner

H. ADDITIONAL RESULTS

Descriptive plots of the status of artillery, air and air defense assets for both models are shown in Figures 4.10 and 4.11 for the next-event model and fixed-interval (t = 0.0025) results, respectively. Since the scenario for both models is the same, the plots are similar.

Red tanks detect the blue APCs as they approach their defenses. The scouts are out of direct fire range, so the red FSCC assigns artillery an indirect fire mission. Approximately 0.10 hours after the APCs are detected, the APCs detect the red tanks. Initially, the tanks are also beyond directly direct fire range, so the blue FSCC assigns their artillery an indirect fire mission. Blue artillery continues this mission until it eventually detects the red artillery rounds and begins counterbattery fire. Similarly, red eventually switches to a counterbattery fire mission.

In this scenario, both artillery batteries have the same rate of fire and P_k against the other, so the mean percent strength remaining curves are generally parallel throughout the course of the battle.

Also annotated on the plots are the results of the air activity. Since blue artillery is executing a mission at the time of the second red tank detection, the FSCC launches the helicopters. The helicopters are killed during 50 percent of the next-event model runs and during 54 percent of the fixed-increment model runs. The mean time of the kills is 0.47 hours for both models.

For this set of runs, the fixed-wing section launches from the air base to attack the red air defense site at time 0.50. It is killed during 42 percent of the next-event model runs and during 62 percent of the fixed-increment model runs. Mean times of the kills are 0.68 hours and 0.69 hours, respectively. Finally, the red air defense mean percent strength remaining is plotted. The fixed-wing section has approximately equal success in both models.

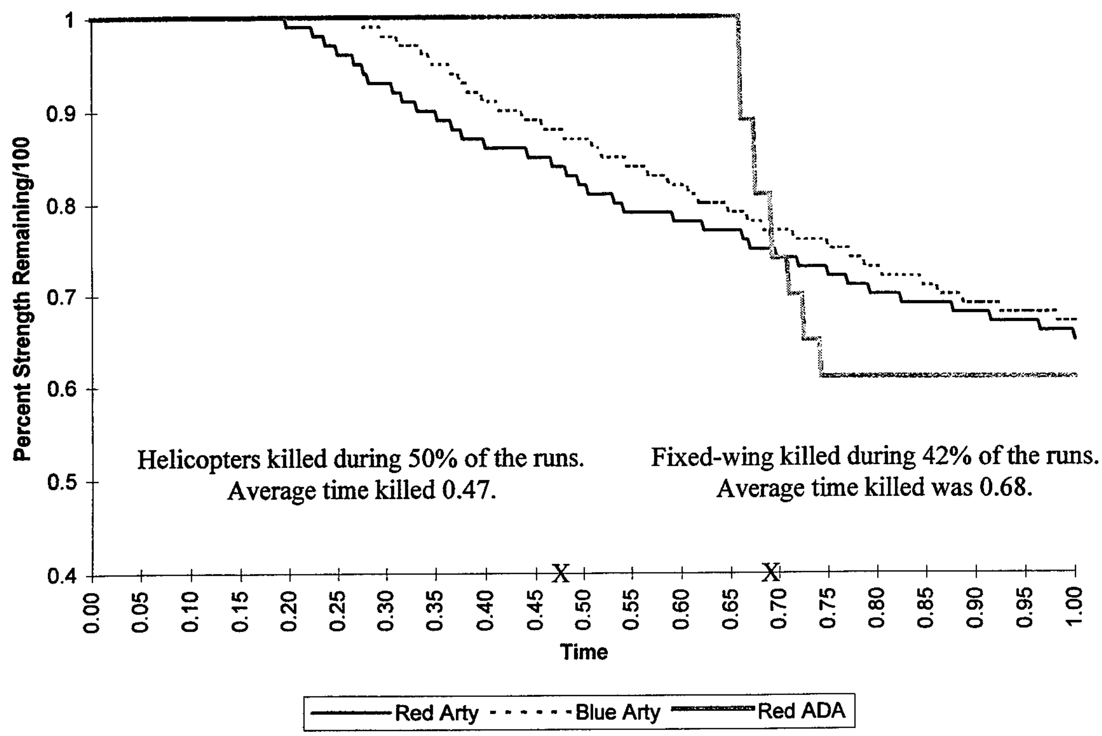

Figure 4.10. Artillery, Air and Air Defense Status for Next-Event Model

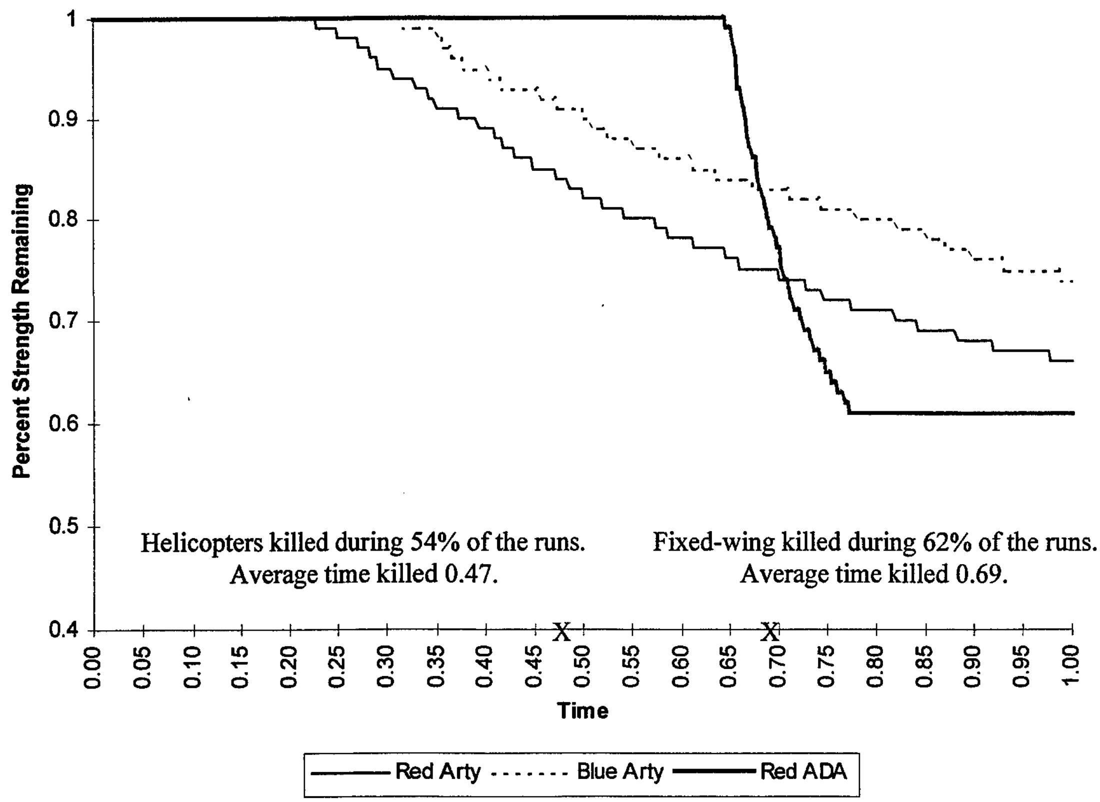

Figure 4.11. Artillery, Air and Air Defense Status for Fixed-Interval Model

Figures 4.12 and 4.13 show the standard deviation plots for the artillery and air defense percent strength remaining, respectively. The standard deviation of red and blue artillery mean percent strength remaining is almost equal for the next-event model, while red artillery strength in the fixed-increment model is slightly higher than that for blue artillery. The standard deviation of the air defense site is approximately equal in both models.

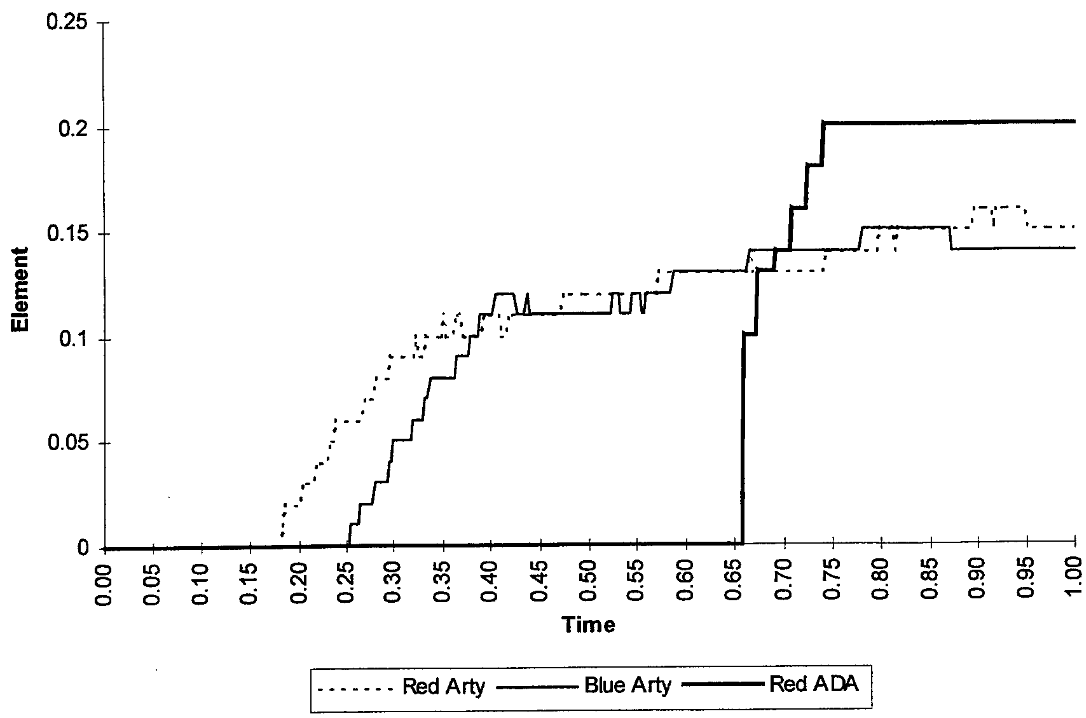

Figure 4.12. Artillery, Air and Air Defense Standard Deviation for Next-Event Model

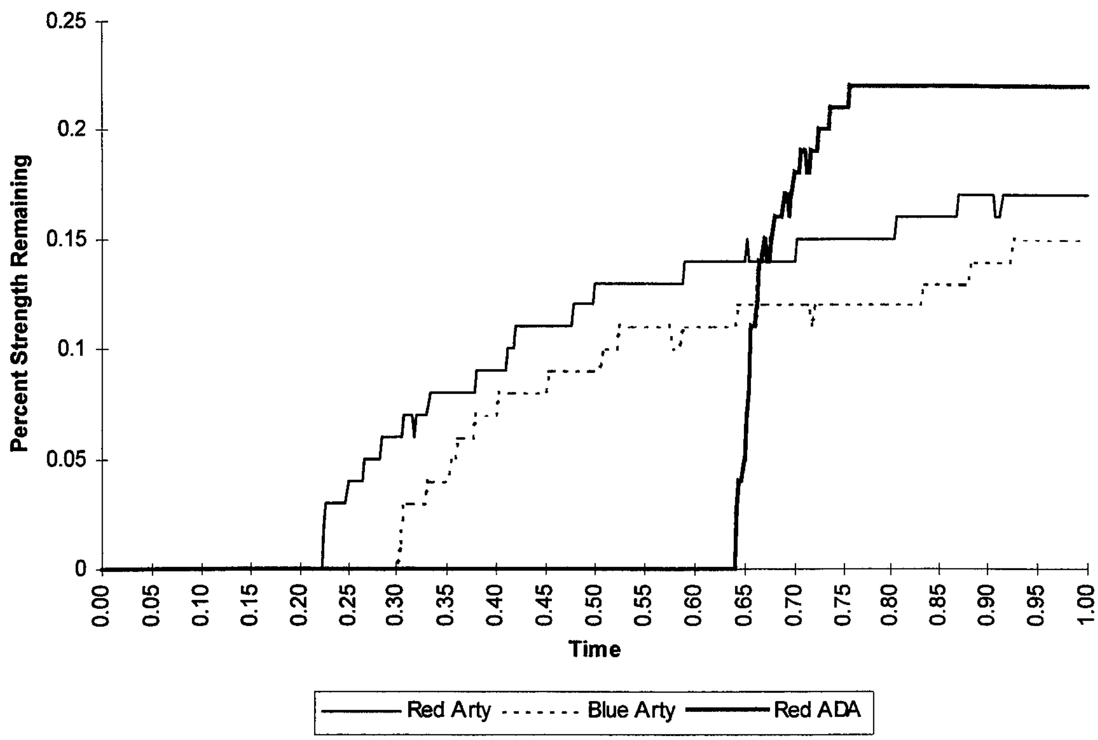

Figure 4.13. Artillery, Air and Air Defense Standard Deviation for Fixed-Interval Model

I. DISCUSSION

In summary, three important aspects of this analysis should be highlighted. First, as the length of the time increment in a fixed-increment model decreases, the results more closely approximate the next-event model results. This appears reasonable if the next-event model is viewed as a fixed-increment model using an infinitely small time increment.

Second, in a fixed-increment model, results can change if the length of the time increment changes. This is an undesirable characteristic to have in a model. Results should vary with varying input data and parameters so that a cause-and-effect relationship can be established. Models using a fixed-increment time advance mechanism need to be

examined for this effect. In all cases, the length of the increment used should be published along with the results.

Finally, in a fixed-increment model, results can change if the sequence of events changes. It may not always be the case that the proper event sequencing is obvious or important. It may also be the case that in a larger model the sequencing effect averages out. In any case, this is another aspect of the model that must be examined when verifying results.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

It is vital that JWARS provides timely, accurate results. To do so, its developers must design and implement a method to represent the impact of the activities of the individual combatants comprising the units depicted in the simulation. This study examined two possible alternatives; a model using a next-event time advance mechanism and one using a fixed increment time advance mechanism. What conclusions can be drawn?

This study served to quantitatively demonstrate the differences between the two time advance mechanisms. Intuition is reinforced with analysis in the following areas.

First, the problem of event sequencing is pervasive in the hybrid model. Like other fixed-increment models before it, the schemes used to compensate for not processing events at the precise time of occurrence can radically influence the results.

Second, if a fixed-increment model must be used, one with a smaller increment may produce more accurate results that one with a larger increment. Of course, the model using the smaller increment will take longer to produce those results.

Finally, the next-event model overcomes the event-sequencing problem but, again, at the cost of an increased runtime.

B. RECOMMENDATIONS

A fast, incorrect result is at least as bad, if not worse than one not received in time to assist with the decision at hand. All other circumstances being equal, a model employing a next-event time advance mechanism will deliver more accurate results than one with a fixed-increment mechanism. The impact of the decisions made by JWARS' users are too important to settle for anything less.

APPENDIX. DATA

Data are organized and input by separate files for miscellaneous, individual combatant and weapon systems. Data enclosed in brakets, [], are unique to the fixed-increment time advance model and change for each 1.0 hour run (i.e., 400 iterations * 0.0025 hour interval = 1.0 hours).

Miscellaneous		
Number of runs	50	
Iterations per run	[400, 200, 100]	
Interval Length (hr)	[0.0025, 0.005, 0.01]	
Blue Maneuver Vehicles		
Total Number	38	
Number of Different Types of Blue Maneuver Vehicles	2	
Vehicle Type (code)	1 (Tank)	
Number	33	
Maximum Speed (kph)	10.0	
Maximum Fuel (hr)	2.0	
Maximum Ammunition Load	40	
Weapon Type (code)	3	
Search Radius (km)	3.0	
X-offset (km, formation information)	0.025	
Y-offset (km, formation information)	0.025	
Target Priority (one for each *j* enemy system)	1 99 99 99 99 99	
λ_{ij} (detections per hr, one for *j* each enemy system)	27.82 0.0 0.0 0.0 0.0 0.0	
Initial Position of Blue Maneuver Vehicles	x	y
	20.000	11.000
	19.975	10.975
	20.025	10.975
	19.950	10.950
	20.050	10.950
	19.925	10.925

	20.075	10.925
	19.900	10.900
	20.100	10.900
	19.875	10.875
	20.125	10.875
	19.850	10.850
	20.150	10.850
	19.825	10.825
	20.175	10.825
	19.800	10.800
	20.200	10.800
	19.775	10.775
	20.225	10.775
	19.750	10.750
	20.250	10.750
	19.725	10.725
	20.275	10.725
	19.700	10.700
	20.300	10.700
	19.675	10.675
	20.325	10.675
	19.650	10.650
	20.350	10.650
	19.625	10.625
	20.375	10.625
	19.600	10.600
	20.400	10.600
Lead Blue Vehicle Route	20.000	30.000
Vehicle Type (code)	2 (Armored Personnel Carrier)	
Number	5	
Maximum Speed (kph)	10.0	

Maximum Fuel (hr)	2.0	
Maximum Ammunition Load	10	
Weapon Type (code)	4	
Search Radius (km)	3.0	
X-offset (km, formation information)	0.05	
Y-offset (km, formation information)	0.05	
Target Priority (one for each *j* enemy system)	1 99 99 99 99 99	
λ_{ij} (detections per hr, one for *j* each enemy system)	27.82 0.0 0.0 0.0 0.0 0.0	
Initial Position of Blue Maneuver Vehicles	x-coordinate	y-coordinate
	19.000	13.000
	18.950	12.950
	19.050	12.950
	18.900	12.900
	19.100	12.900
Lead Blue Vehicle Route	19.000	16.000
Blue Artillery		
Type (code)	3 (Artillery)	
Maximum Ammunition	200	
Weapon Type (code)	5	
Search Radius	0.01	
Target Priority (one for each *j* enemy system)	2 3 1 99 99 4	
λ_{ij} (detections per hr, one for *j* each enemy system)	0.0 0.0 40.0 0.0 0.0 0.0	
Initial Position	20.000	5.000
Degradation Factor	0.90	
Breakpoint	0.30	
Rounds in Salvo	6	
Blue Helicopter		
Type (code)	4 (Helicopter)	
Maximum Speed (kph)	80	
Maximum Ammunition	8	

Weapon Type (code)	7	
Search Radius	6.0	
Target Priority (one for each *j* enemy system)	2 99 99 99 99 1	
λ_{ij} (detections per hr, one for *j* each enemy system)	27.82 0.0 0.0 0.0 0.0 20.0	
Initial Position	5.000	5.000
Number of Attack Positions	7	
Attack Position Coordinates	5.000	20.000
	8.000	25.000
	14.000	18.000
	18.000	16.000
	20.000	22.000
	22.000	25.000
	24.000	20.000
Blue Fixed-Wing		
Type (code)	5 (Fixed-Wing)	
Maximum Speed (kph)	200	
Maximum Ammunition	8	
Weapon Type (code)	8	
Search Radius	6.0	
Target Priority (one for each *j* enemy system)	2 99 99 99 99 1	
λ_{ij} (detections per hr, one for *j* each enemy system)	27.82 0.0 0.0 0.0 0.0 20.0	
Initial Position	0.000	0.000
Number of Attack Positions	7	
Attack Position Coordinates	5.000	8.000
	8.000	25.000
	14.000	18.000
	18.000	16.000
	20.000	22.000
	22.000	25.000
	24.000	20.000

Red Maneuver Vehicles		
Number of Red Maneuver Vehicles	16	
Number of Different Types of Red Maneuver Vehicles	1	
Vehicle Type (code)	1 (Tank)	
Number	16	
Maximum Speed (kph)	10.0	
Maximum Fuel (hr)	2.0	
Maximum Ammunition Load	40	
Weapon Type (code)	1	
Search Radius (km)	4.0	
Target Priority (one for each j enemy system)	2 3 99 1 99 99	
λ_{ij} (detections per hr, one for j each enemy system)	83.46 27.82 0.0 30.0 0.0 0.0	
Initial Position of Red Maneuver Vehicles	x-coordinate	y-coordinate
	20.000	18.000
	20.100	18.100
	20.200	18.000
	20.300	18.100
	20.000	18.200
	20.050	18.050
	19.950	18.050
	19.900	18.100
	19.850	18.050
	19.800	18.000
	19.750	18.050
	20.150	18.050
	20.250	18.050
	19.700	18.100
	19.650	18.050
	20.350	18.050
Red Artillery		
Type (code)	3 (Artillery)	

Maximum Ammunition	200	
Weapon Type (code)	8 (Red Artillery)	
Search Radius	0.01	
Target Priority (one for each j enemy system)	2 3 1 99 99 4	
λ_{ij} (detections per hr, one for j each enemy system)	0.0 0.0 40.0 0.0 0.0 0.0	
Initial Position	20.000	30.000
Red Air Defense		
Type (code)	6 (Air Defense Site)	
Maximum Ammunition	12	
Weapon Type (code)	9	
Search Radius	20.0	
Target Priority (one for each j enemy system)	99 99 99 2 1 99	
λ_{1j} (detections per hr, one for j each enemy system)	0.0 0.0 0.0 60.0 60.0 0.0	
Initial Position	10.000	30.000
Weapons		
Number of Weapon Systems	9	
Type (code)	1 (Red Main Tank Gun)	
Opening Engagement Range (km)	2.6	
P_{1j} (P_k of weapon type1 against combatant type j)	0.9 0.4 0.0 0.5 0.0 0.0	
Bonder Exponent	1.0	
Rate of Fire (rounds per minute)	0.95	
Type (code)	3 (Blue Main Tank Gun)	
Opening Engagement Range (km)	2.0	
P_{3j} (P_k of weapon type3 against enemy combatant type j)	0.4 0.0 0.0 0.0 0.0 0.0	
Bonder Exponent	1.0	
Rate of Fire (rounds per minute)	0.5	
Type (code)	4 (Blue Anti-Tank Missile)	

Opening Engagement Range (km)	2.0
P_{4j} (P_k of combatant type 4 against enemy combatant type j)	0.4 0.0 0.0 0.0 0.0 0.0
Bonder Exponent	0.5
Rate of Fire (rounds per minute)	0.5
Type (code)	5 (Blue Artillery)
Opening Engagement Range (km)	30.0
P_{5j} (P_k of combatant type 5 against enemy combatant type j)	0.02 0.02 0.04 0.0 0.0 0.0
Bonder Exponent	0.05
Rate of Fire (rounds per minute)	3
Type (code)	6 (Precision-Guided Munition)
Opening Engagement Range (km)	15.0
P_{6j} (P_k of combatant type 6 against enemy combatant type j)	0.3 0.0 0.0 0.0 0.0 0.7
Bonder Exponent	1.0
Rate of Fire (rounds per minute)	1.0
Type (code)	7 (Anti-Tank Missile)
Opening Engagement Range (km)	3.0
P_{7j} (P_k of combatant type 7 against enemy combatant type j)	0.3 0.0 0.0 0.0 0.0 0.5
Bonder Exponent	0.5
Rate of Fire (rounds per minute)	1.0
Type (code)	8 (Red Artillery)
Opening Engagement Range (km)	30.0
P_{8j} (P_k of combatant type 8 against enemy combatant type j)	0.02 0.02 0.04 0.0 0.0 0.0
Bonder Exponent	0.05
Rate of Fire (rounds per minute)	3
Type (code)	9 (Surface-to-Air Missile)
Opening Engagement Range (km)	20.0
P_{9j} (P_k of combatant type 9 against enemy combatant type j)	0.0 0.0 0.0 0.2 0.2 0.0

Bonder Exponent	0.5
Rate of Fire (rounds per minute)	0.3
Delay to Switch Targets (hr)	0.01

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